



## METHOD USING SECONDARY ORIENTATION TO TUNE BUCKET NATURAL FREQUENCY

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5 Government has certain rights in this invention.

### BACKGROUND OF THE INVENTION

This invention relates to gas turbine bucket construction and, more particularly, to using secondary orientation to tune turbine bucket natural frequencies.

10 As a rotational component in a gas turbine engine, the turbine blade or turbine bucket experiences different dynamic stimuli due to the aerodynamic disturbances from, for example, the up- and down-stream nozzles, the combustor cans, the tip shrouds, etc. When any of these stimulus  
15 frequencies is close enough to the natural frequency of the rotational turbine bucket, resonance may occur that will likely cause failures, usually catastrophic, to the bucket due to high cycle fatigue. Indeed, a large number of engine failures in the field can be traced back to the root cause of vibration related failures. Thus, it is important in bucket design to avoid resonance during operation by a sufficient margin.

20 Previously, tuning of bucket natural frequencies has been accomplished using airfoil thickness to chord ratio, trailing edge wedge angle, trailing edge mass, airfoil wall thickness, cooling cavity size and number, tip shroud or cap, and camber. These previous methods, however, typically  
25 require the alteration of some physical feature of the bucket such as bucket weight or shape and/or increased production costs or altering the flex modes when only torsional or stripe modes are needed to be tuned. It is thus desirable to effect tuning of bucket torsional and stripe mode natural frequencies without altering any bucket physical features, without increasing



bucket manufacturing cost, and without affecting the turbine bucket flexure frequencies.

## BRIEF SUMMARY OF THE INVENTION

In an exemplary embodiment of the invention, a method of  
5 manufacturing a turbine bucket includes (a) investment casting the turbine bucket with a single crystal alloy, and (b) tuning a natural frequency of the turbine bucket without modifying physical features of the turbine bucket. Step (b) may be practiced by tuning the natural frequency of the turbine bucket without affecting turbine bucket weight or turbine bucket shape. Step (b) may  
10 also be practiced by tuning torsional and stripe mode frequencies without affecting flexure mode frequencies of the turbine bucket. In this context, step (b) is preferably practiced by, prior to step (a), placing the crystal seed along a desired direction according to an orientation relative to the engine axial direction.

15 In another exemplary embodiment of the invention, a method of tuning turbine bucket natural frequency includes (a) placing the crystal seed along a desired orientation relative to the engine axial direction, and (b) investment casting the turbine bucket with a single crystal alloy, wherein the desired orientation is selected to tune torsional frequencies without affecting flexure  
20 frequencies.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 illustrates a crystal orientation relative to engine orientations;

FIGURE 2 is a graph showing the effect of secondary orientation on 1T  
25 and 2T frequencies; and

FIGURE 3 is a graph showing the effect of secondary orientation on 1-2S and 1-3S frequencies.



## DETAILED DESCRIPTION OF THE INVENTION

With reference to FIGURE 1, in a single crystal alloy, the material directions along the X' and Y' axes are termed secondary orientation, while that along the Z' direction is termed as the primary orientation. The secondary orientation is defined by the angle  $\theta_s$  between the engine axial direction X and the material direction X', which is the same as the angle between the engine tangential direction Y and the material direction Y'.

Operating frequencies of turbine buckets can be determined in the design phase using engineering models and the like as would be apparent to those of ordinary skill in the art. The data for FIGURES 2 and 3 is based on known Finite Element (FE) Analyses (known as ANSYS code) and is validated through engine tests. Similar engineering models by FE analyses can be used to determine bucket natural frequencies. As noted, it is important to avoid resonance by a sufficient margin to improve operating efficiency, and it thus may be necessary to "tune" the natural frequencies of a turbine bucket.

In a bucket of single crystal alloy, the shear modulus that determines the torsional frequencies is dependent on the secondary orientation  $\theta_s$ . The tensile modulus along the radial direction that determines the flexure frequencies, on the other hand, is insensitive to the secondary orientation. Thus, with the method of the present invention, the secondary orientation can be used to tune the torsional frequencies without affecting the flexure frequencies. FIGURE 2 shows the change of 1T and 2T frequencies as a function of the secondary orientation. FIGURE 3 shows the change of 1-2S and 1-3S frequencies as a function of the secondary orientation. It is known that changes in the secondary orientation will not affect the flexure frequencies (such as 1F, 2F, etc.). Moreover, the change in secondary orientation does not entail changes in turbine bucket weight and shape. To implement certain preferred secondary orientation in an investment casting



process is a relatively easy operation, thus the impact is minimal on manufacturing cost.

As noted, the data for FIGURES 2 and 3 is derived from FE analyses. First analyses are conducted by incorporating the secondary orientation in the engineering model, then the results are correlated with the engine test results. Subsequently, the secondary orientation is varied, and the curves are completed.

Investment casting with a single crystal alloy is known, and the details of the casting process will not be described herein. A related investment casting process is described in commonly-owned U.S. Patent No. 5,713,722, the contents of which are herein incorporated by reference.

In the investment casting process, the secondary orientation is controlled by placing the crystal seed along a desired direction. Placing of the crystal seed in the investment casting process does not affect the physical features of the turbine bucket, such as the bucket weight or shape, and does not entail any additional manufacturing operation or cost. As shown in FIGURES 2 and 3, the desired direction of the crystal seed or secondary orientation is selected to effect a desired percentage change in turbine bucket natural frequencies.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.